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# Chapter 4 Reduce Exposure to Dermal Hazards

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Estimates from the Bureau of Labor Statistics (BLS) indicate that more than 13 million workers in the United States are potentially exposed to chemicals that can be absorbed by the skin. Exposures to chemicals in the workplace continue to rank as a leading cause of illness and death in the United States resulting in an estimated 60,000 deaths and more than 800,000 illnesses each year. [1, 2] Contact dermatitis, a skin condition resulting from chemicals absorbed through a worker's skin, is one of the most common chemically induced causes of occupational illness accounting for 10 to 15 percent of all occupational illnesses at an annual cost of at least $1 billion.[3]

The skin is classified as the largest organ of the human body, and serves as the natural dermal barrier to injury or illness from contact with hazardous chemicals. A worker's skin may be exposed to hazardous chemicals through direct contact with contaminated surfaces, deposition of aerosols, immersion, or splashes. The route of entry into the body, or whether it remains in external contact with the skin determines the type and extent of injury or illness that results. This varies with the characteristics of the chemical and the condition of the skin to serve as an effective dermal barrier against that hazard.

Occupational skin diseases and disorders resulting from contact with the skin include contact dermatitis, eczema, or rash caused by primary irritants and sensitizers or poisonous plants; oil acne; chrome ulcers; and chemical burns or inflammations. Penetration or permeation through the skin layer can result in percutaneous injuries (injuries through the skin, including punctures with contaminated sharp instruments such as needles and scalpels), or illnesses from contact with mucous membranes of the eyes, nose, or mouth or through exposed broken or abraded skin.

The first recommendations of Threshold Limit Values (TLV) for exposure to chemicals were prepared by the American Conference of Governmental Industrial Hygienists (ACGIH) in the mid-1930s. Later, legally enforceable Permissible Exposure Limit (PEL) values were established by the Occupational Safety and Health Administration (OSHA). From these beginnings, emphasis in occupational hygiene primarily has been on the measurement and control of airborne exposures to chemicals. However, many chemicals in the workplace present primarily a surface contaminant hazard, coming in contact with the worker through transfer to the skin. Furthermore, a significant component of many chemical exposures can be through dermal contact with chemical vapors, liquids, or solids, in addition to respiratory exposures. There remains a relatively poor understanding of how to evaluate skin exposures, how to estimate risk and most importantly, how to prevent exposures. Guidelines are not available to provide appropriate guidance to assess safe levels of chemicals for dermal exposure. Information obtained from conventional barrier tests is not directly applicable to support the proper selection of chemical protective clothing.

Where dermal exposure hazards are encountered, the use of Personal Protective Technology (PPT) functions to provide a barrier between the worker's skin (dermal layer) and the hazard. The effectiveness of clothing or garment barrier protection can be a function of the materials used in construction of the barrier, construction methods (e.g. seams, fastenings) and also the design of the barrier to conform to the area of the body requiring protection.

The use of protective garments as barriers for dermal exposure can also introduce physiological and/or ergonomic limitations on the wearer. The added weight of a protective garment or the restricted mobility introduced can result in added stress for the wearer. Physiological and/or ergonomic burdens can present a disincentive or added injury risk for the worker.

In order to address these concerns, the PPT Program has identified the following Objectives in support of its Goal 2 to reduce exposure to dermal hazards:

*Objective 1* Improve chemical/barrier protective clothing testing and use practices to reduce worker exposure to chemical dermal hazards

*Objective 2* Improve emergency responder protective clothing to reduce exposure to thermal, biological, and chemical dermal hazards

*Objective 3* Investigate physiological and ergonomic impact of protective ensembles on individual wearers in affecting worker exposure to dermal hazards

Tactical approaches used to accomplish the Program dermal strategic goal are:

- Conduct research on dermal protective technologies,
- evaluate personal dermal protective equipment,
- develop standards and guidance for dermal protective equipment, and
- conduct Research-to-Practice (r2p) programs for Program activities.

Other forms of barrier protection include protective creams and lotions applied directly to the skin. Effective use of protective creams and lotions introduces issues of skin compatibility and possible allergic reactions. Insect repellents are an example. The PPT Program does not currently address the issues of these types of protective barriers.

The narratives that follow describe PPT Program efforts, outputs and outcomes for each objective.

## 4.1 Improve Chemical/Barrier Protective Clothing Testing and Use Practices to Reduce Worker Exposure to Chemical Dermal Hazards

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### Issue

The most common approach to protect against hazardous chemical contact with skin is the issuing of gloves and other chemical protective clothing to workers. More than $800 million of protective gloves are sold in the United States annually.[4]

Typically, protective clothing and gloves are selected and their duration of wear is estimated based on comparisons of laboratory test data. Those who select the protective items often fail to verify their selections by conducting performance tests during use. This failure poses a common but potentially serious hazard to workers. Although methods are available for assessing permeation rates during actual use, such testing is unlikely without acceptable guidance criteria for decision making. Additionally, the costs of most chemical protective clothing used for highly toxic exposures or routine exposures are substantial. This makes reusability, rather than disposal, a reality. Therefore, scientifically based and verified strategies for decontamination and reuse to reduce exposure to chemical dermal hazards are essential.

In addition to understanding when and how to apply chemical protective clothing for reducing dermal exposure, there is the issue of understanding performance limitations. Guidelines established by the EPA require use of a totally encapsulating chemical protective suit for a terrorist event involving unknown hazards. Such chemical protective clothing is expensive and its decontamination is essential. Although the OSHA has required decontamination of protective clothing under two regulations, i.e., the general Personal Protective Equipment (PPE) standard – 29 Code of Federal Regulations (CFR) 1910.132[5] and the Hazardous Waste Operation and Emergency Response Standard – 29 CFR 1910.120[6], it does not define how and when chemical protective clothing (CPC) should be cleaned, decontaminated, or retired to ensure its effectiveness.[7] Adequate evaluation of the continued efficacy of chemical protective clothing with use is essential to protect workers who rely on chemical protective clothing including gloves.

### Approach

General research needs for reducing exposure to chemical dermal hazards originally were identified and included in the National Occupational Research Agenda (NORA), as a direct result of the 1998 National Institute for Occupational Safety and Health (NIOSH)-conducted workshop to establish the foundation for “Setting the Research Agenda for Control of Workplace Hazards for the 21st Century”.[8] This workshop stimulated a number of topics related to dermal protection, some of which were undertaken by the PPT Program. For example, a review of Biological and Chemical Protection Research Needs with the recommendation of biological/chemical protective clothing decision logic was completed in 2003. More recently, a number of studies were initiated within the PPT Program to address reducing exposure to chemical dermal hazards. The studies were conducted to establish solutions for reducing exposure to chemical dermal hazards where limited workplace exposures exist to serve as pilot programs to demonstrate PPT Program effectiveness for this objective.[9]

One specific need for dermal protection research identified in NORA was the lack or inadequacies of current methods for measuring actual permeation of chemicals through gloves and other forms of chemical protective clothing in a manner that represents PPT in-use scenarios. Previous research conducted by the PPT Program during the 1980s had evaluated several different aspects of permeation to improve industry understanding or investigate specific test problems. PPT program activities encompassed different assessments to evaluate variations in material performance due to polymer formulations, the effects of temperature, and permeation of chemical mixtures. Additional research investigated different methods for performing permeation measurements.

More recent PPT Program research continued to evaluate in-use methods of assessing permeation through chemical protective gloves. This research involved the development and evaluation of colorimetric/sorbent indicators that could be worn by individuals to measure levels of chemical dermal exposure and thus determine the barrier effectiveness of gloves. Colorimetric indicators change color when exposed to specific substances (hazards) thus providing a visual indication of the hazard. Specific research was carried out by identifying specific colorimetric sorbents, characterizing their effectiveness in capturing particular permeating chemicals. Their utility underneath glove materials in a laboratory setting and when worn by workers also was determined in this research.[10-12] The research was successful for several different chemicals (e.g. toluene and acetone) and was able to demonstrate differences in measured permeation for various glove materials (including neoprene, Guardian butyl rubber, and nitrile synthetic rubber)

Many items of CPC and gloves, although providing adequate protection, are too expensive to be thrown away. The PPT Program initiated research studies in 2001 to evaluate the ability to effectively decontaminate selected glove materials using specific chemicals and industry available decontamination methods. The research studies involved a total of 260 permeation tests. Results were collected on each material/chemical combination for up to ten exposure/ decontamination cycles. From this research, it was found that one decontamination method, elevated temperature heating, was an effective method in removing the solvents from several of the selected glove materials. This finding meant that multiple reuses of some chemical protective gloves could be safe if effective decontamination methods are used.

The American Industrial Hygiene Association (AIHA) realized the value of this research and solicited the PPT Program project officer to lead the effort to develop AIHA Guideline 6 – 2005[13], Guideline for the Decontamination of Chemical Protective Clothing and Equipment. This guideline provides information for making decisions on decontamination method selection, plans, decontamination facilities, reuse of decontaminated clothing, equipment, and a variety of other considerations that must be included if an effective and safe decontamination program is to be developed and used.

As part of this research effort, the PPT Program undertook the development of a formal method for calculating permeation parameters for analysis of permeation testing data. This effort paralleled an industry need related to chemical protective clothing as identified in the Standards Development Organizations (SDOs), most notably the American Society for Testing and Materials (ASTM). In June 2005, the lead NIOSH PPT researcher presented the “Permeation

Calculator" concept to the ASTM F23 Protective Clothing Committee. This presentation fostered development and implementation of a Memorandum of Understanding between NIOSH and ASTM for cooperative development of standards to address PPT areas of mutual interest. The PPT researcher's participation in the ASTM committee and presentations to other industry groups such as the International Safety Equipment Association (ISEA) provided opportunities for stakeholder review of the product. Increased user awareness and feedback helped form the project output into an industry usable product. Following the stakeholder review, a systematic Scientific Peer Review was conducted first using NIOSH internal scientific reviewers, followed by a scientific review using external reviewers.

The Permeation Calculator was issued as NIOSH Publication No. 2007-143C Permeation Calculator Version 2.4 in June 2007.[14] The Permeation Calculator has been reproduced in compact disk media and disseminated at relevant conferences and workshops and is available for download on the PPT Program website.

**Output and Transfer Highlights**

PPT program research provided data relevant to decontamination and permeation issues with chemical protective clothing. The PPT Program research on the use of colorimetric sorbents for measuring chemical permeation was documented in a series of peer-review articles. The articles described specific sorbents used, methods for measuring permeation, and provided example results for specific chemicals.

PPT Program research on the Permeation Calculator was featured in six presentations at five conferences and published in eight peer reviewed manuscripts covering these important industry issues and needs.[10-12, 15-25]

Decontamination and exposure effects research has taken the form of products by industries that apply information from the research to reduce exposure to chemical dermal hazards. PPT Program collaborated with the AIHA to facilitate translation of research findings into recommended user practice. Decontamination research findings were documented in a final report currently under internal NIOSH review.[13, 20-24]

PPT Program dermal research has increased the understanding of decontamination and reuse of chemical protective clothing. Peer reviewed manuscripts[26-29] provide examples of PPT Program research in this area.

Work on the Permeation Calculator has resulted in a robust, peer-reviewed software program that can be used by industry to increase the ease and accuracy of permeation test calculations. The Permeation Calculator as a final product was issued as NIOSH Publication No. 2007-143C Permeation Calculator Version 2.4 in June 2007.[14] The Permeation Calculator has been reproduced in compact disk media and disseminated at relevant conferences and workshops. It is also available on the PPT Program website.[14]

A PPT Program researcher presented research findings at two ISEA Hand Protection committee meetings in 2004 and 2005. The committee provided positive feedback regarding the relevance of the work. The title of the 2005 presentation was “Permeation Calculator”. The title of the 2004 presentation was “Decontamination and Reusability of Chemical Protective Clothing and Gloves”. The ISEA Technical Director indicated the information presented was excellent and has significant relevance to the recommendations made to users on the service life of their hand protection. The committee urged the PPT Program to continue this work with additional trials and challenge chemicals.

In a related effort, the PPT program conducted a collaborative research project titled “Chemistry of functional finishing: Self-decontaminating materials” with the University of California, Davis. This project won the director's award at the 12th National Textile Center's (NTC) annual forum in February 2004. This award was for highest ranking study selected by NTC’s Technical Advisory Committee. The collaboration resulted in one publication in a peer-reviewed journal and several conference presentations.

PPT Program work on the Permeation Calculator has followed related work intended to reduce exposure to chemical dermal hazards through improving information that informs industry of chemical hazards and clothing performance limitations. Results from skin notation research were presented at two conferences and published in one peer reviewed manuscript.[4, 30, 31]

The Program was responsible for or made contributions to the following web materials:

- Website posting of NIOSH Safety and Health Topic site for Skin Exposures & Effects (http://www.cdc.gov/niosh/topics/skin)[32]
- Website posting of research projects related to dermal exposures: (http://www.cdc.gov/niosh/topics/skin/skinresearch.html)[33]
- Website posting of NIOSH Chemical Safety site (http://www.cdc.gov/niosh/topics/chemical-safety/)[34]
- Website posting of Immune, Dermal and Infectious Diseases Program (http://www.cdc.gov/niosh/programs/ididisease.html)[35]
- Website posting of Pesticide Illness and Injury Surveillance Program (http://www.cdc.gov/niosh/topics/pesticides)[36]

**Intermediate Outcomes**

The work on new permeation test techniques involving colorimetric indicators established new techniques to be used by industry and also provided the basis for further developments to improve permeation testing for reducing dermal hazards. Based on PPT Program research, some of the product technology in the form of glove permeation detection aids has been commercialized by Colorimetric Industries, Inc.[37] The product, Perma-Tec™ colorimetric indicators are specialized adsorbents that provide color changes in the event of chemical exposure at designated concentrations. The indicators are designed as thin, unobtrusive pads that can be worn underneath gloves to show when gloves break down or where exposures exceed recommended limits.

An intermediate outcome of the decontamination research program is AIHA Guideline 6 – 2005, Guideline for the Decontamination of Chemical Protective Clothing and Equipment.[13] This guideline provides information for making decisions on decontamination method selection, plans, decontamination facilities, reuse of decontaminated chemical protective clothing and equipment and a variety of other considerations that must be included for an effective and safe decontamination program. As of June 2007, 134 copies of the Decontamination Guideline have been sold by the AIHA. This reference serves as the only current source of detailed information on decontamination procedures for chemical protective clothing.

The Permeation Calculator will be incorporated into at least two ASTM standards currently being developed: 1) ASTM Work Item entitled "New Standard Practice for Permeation Testing Data Analysis by Use of a Computer Program" (http://www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/WORKITEMS/WK9186.htm?L+mystore+mvxz5595 ) and 2) ASTM Work Item entitled "New Test Method for Measurement of Cumulative Permeation of Toxic Industrial Chemicals through Protective Clothing Materials" (http://www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/WORKITEMS/WK16014.htm?L+mystore+xdah6267). In addition, ASTM F23 will incorporate the Permeation Calculator into the next version of ASTM F739 standard entitled Permeation of Liquids and Gases through Protective Clothing Materials under Conditions of Continuous Contact for data analysis.

One significance of the Permeation Calculator is that it will easily permit industry to transition from one form of material measurement (breakthrough time) to a different measurement (cumulative permeation), thereby allowing industry to apply toxicity limits to the selection of protective clothing.

**Progress Toward Intermediate and End Outcomes**

Tools for indicating and calculating protective performance of chemical protective gloves and other garments have been established through the PPT program activities. The tools were developed with stakeholder review and input and in conjunction with consensus SDOs standards development procedures. The purchase of AIHA guidelines, distribution and availability of Permeation Calculator software and the marketing activities for colorimetric indicators are early indicators of the successful transfer of PPT Program outputs.

**What's Next?**

The PPT Program will continue and expand its research concerning the measurement of the permeation of hazardous chemicals through protective clothing. Specifically, the development of a standard test method for the measurement of the cumulative permeation of toxic industrial chemicals will be investigated.

This effort is a collaboration between the PPT Program and the Technical Support Working Group (TSWG) of the Department of Defense (DoD). The essence of the project is to tie permeation test methods to actual challenge levels and to link the reportable information, or end points of the test, to actual acceptable toxic exposures. Current test methods apply arbitrary limits and these limits have a profound effect on the availability of material technologies to prevent dermal chemical exposures. Though the project is positioned primarily to address needs for terrorism protection from exposing emergency responders to the use of toxic industrial chemicals, it has ramifications for the way that all permeation testing is conducted and used. The PPT Program will play a pivotal role in this project in specifically developing the next generation method for permeation testing of chemical protective clothing and will have substantial input to the how end points for testing are established.

The PPT Program will initiate new research investigating the penetration characteristics of nanoparticles through protective clothing. The effectiveness of protective clothing materials in preventing the penetration of nanoparticles will be investigated. Nanoparticles are increasingly being used by industry in new products (this work parallels other research by the PPT Program for respiratory protection). The outputs of this project will provide methodologies to assess protective clothing performance that currently do not exist and will increase industry understanding of the types of protective strategies that can be applied to reduce dermal exposure to hazardous nanoparticles.

Another new research area planned to be investigated involves aerosol penetration studies. The objective of this project is to develop innovative methodology for measurement of aerosol particle penetration through protective clothing and ensembles. A test method for aerosol particles including nanoparticles that does not depend on filtration will be developed.

Lastly, an effort will be conducted to develop requirements that address the design and performance of air-fed protective ensembles. Air-fed ensembles are unique because they provide both inhalation and dermal protection as either an airline or powered air-purifying respirator are affixed to a suit and no other supplemental respiratory protection is used. The PPT Program effort will address both dermal and respiratory protection issues. The ensembles are not covered by any standards.

The PPT Program plans to leverage its agreement with ASTM for standards development. This relationship provides opportunities for standards development that enable PPT Program research to reach a broad base of worker populations across multiple industry sectors.

**List of Outputs**

*Peer Reviewed Publications*

Gao P, King WP, Shaffer R [2007]. Review of chamber design requirements for testing of personal protective clothing ensembles. Submitted to the Journal of Occupational and Environmental Hygiene for publication, 4:562-571. [38]

Fei X, Gao P, Shibamoto T, Sun G: [2006] Pesticide detoxifying functions of N-halamine fabrics. Archives of Environmental Contamination and Toxicology, 51: 509-514. [39]

Gao, P., N. El-Ayouby, and J. Wassel, Change in permeation parameters and the decontamination efficacy of three chemical protective gloves. Am Ind Med, Apr, 2005. 47(2): p. 131-134.[16]

Gao, P. and B. Tomasovic, Change to Tensile Properties of Neoprene and Nitrile Gloves After Repeated Exposure to Acetone and Thermal decontaminations. J Occup Environ Hyg, 2005. **2**(11): p. 543-552.[26]

Pollock, D., et al., Dusting off: NIOSH develops a new method to clean dust-soiled work clothes. Rock Prod., 2005. 108(3): p. 30-34.[27]

Vo, E., Application of colorimetric indicators and thermo-hand method to determine base permeation through chemical protective gloves. J Occup Environ Hyg, Dec, 2004. 1(12): p. 799-805.[22]

Vo, E., et al., The thermo-hand method: evaluation of a new indicator pad for acid permeation of chemical protective gloves. Am Ind Hyg Assoc J, 2003. 64(6): p. 771-776.[25]

Vo, E., A new technique to determine organic and inorganic acid contamination. Analyst, 2002. 127(1): p. 178-182.[19]

Boeniger, M. and T. Klinger, In-use testing and interpretation of chemical-resistant glove performance. Appl Occup Environ Hyg, 2002. 17(5): p. 368-378.[4]

Vo, E., A critique of Assumptions about Selecting Chemical-Resistant Gloves: A Case for Workplace Evaluation of Glove Efficacy. Appl Occup Environ Hyg, 2002. 17(5): p. 360-367.[20]

Vo, E., et al., A quantitative study of aromatic amine permeation through protective gloves using amine adsorptive pads. AIHA J , Nov-Dec, 2000. 61(6): p. 837-841.[24]

Vo, E. and S. Berardinelli, Determination of alkylamine permeation through protective gloves using aliphatic amine pads. J Environ Monit, 1999. 1(6): p. 545-456.[23]

Vo, E., S. Berardinelli, and R. Hall, Recovery of some common solvents from protective clothing breakthrough indicator pads by microwave-solvent extraction and gas chromatography. Analyst, 1999. 124(6): p. 941-944.[29]

*Conferences and Presentations*

Gao P, Tomasovic B, (EG&G), Stein L, and Landsittel D, Gergel M, Patnaik R(ICS Laboratories, Inc., Brunswick, OH). Statistical analyses of the decontamination efficacy of chemical protective clothing. Presentation at the American Industrial Hygiene Conference and Exposition, Philadelphia, PA (2007).[40]

Shaffer R. [2007] Update on Nanoparticle Filtration, Respirator, and PPE Research at NIOSH. Ask the Experts: An Update on NIOSH Research in Nanotechnology. Round table discussion at the American Industrial Hygiene Conference and Exposition, Philadelphia, PA June 2-7.[41]

Shaffer, R. [2007] Overview of NIOSH Nanotechnology Research. Presentation at the Air & Waste Management Association, Pittsburgh, PA, June 29.[42]

Vo E, Murray D, Scott T, Attar A. [2007] Development of a Novel Colorimetric Indicator for Detecting Aldehydes. The International Journal of Pure and Applied Analytical Chemistry, Atlanta, 73: 87-94.[43]

Collins-Hansen, I., et al., Field evaluation of gloves and protective clothing against organic solvents during auto body spray painting, in Am. Ind. Hyg. Conf. Expo. 2006.[10]

Pollock, D., et al., A new method to clean dust from soiled work clothes, in Proceedings of the 11th U.S./North American Mine Ventilation Symposium. 2006: University Park, Pennsylvania, June 5-7.[28]

Shaffer R, Rengasamy A, Gao P [2006]. Penetration of nanoparticles through respirators and protective clothing. Poster Presentation, presented at the International Conference on Nanotechnology Occupational & Environmental Health and Safety, Cincinnati, OH 4-6 Dec, 2006.[44]

Shaffer R, Gao P, Rengasamy A [2006]. Penetration of Nanoparticles Through Respirators and Protective Clothing, Presented at the International Conference on Elevated Wind Studies, September 25-26, 2006 in Arlington, VA.[45]

King WP, Yeso M,Gao P: Coating evaluation for a newly developed passive aerosol sampler based on magnets for determination of particle penetration through protective ensembles. American Industrial Hygiene Conference & Exposition, Chicago, Illinois, May 13 – 18, 2006.[46]

Shaffer R [2006]. Controls/PPE. Talk given at the Tech Talks session at the International Conference on Nanotechnology Occupational & Environmental Health and Safety, Cincinnati, OH 4-6 Dec, 2006.[47]

King W, Gao P [2005] A passive aerosol sampler for evaluation of personal protective ensembles, presented at the Advanced Personal Protective Equipment: Challenges in Protecting First Responders October 16-18, 2005.[48]

Gao, P [2005] “Occupational and Environmental Exposures of Skin to Chemicals” conference June 11 and June 14, 2005, Stockholm, Sweden. Presented a poster entitled “Two new permeation parameters for evaluating decontamination efficacy of chemical protective clothing materials”. [49]

Vo, E [2005] “Occupational and Environmental Exposures of Skin to Chemicals” conference June 11 and June 14, 2005, Stockholm, Sweden. Presented a poster entitled “Development of Colorimetric Indicators: A New Technique to Determine Acid, Base, and Aldehyde Contaminations”. Evanly’s poster was selected as the best poster in the research design and new method development category.[50]

Gao P, Tomosovic B, Chung D[2005]. Development of a computer program for automating permeation testing data analysis. American Industrial Hygiene Conference & Exposition, Anaheim, California, May 23 – 27, 2005.[51]

Gao P, Sun G (University of California, Davis): “Detoxification of Carbamate Pesticides by Halamine Structures” presented at the 229th American Chemical Society National Meeting, San Diego, California on March 13–17, 2005.[52]

Gao, P., B. Tomasovic, and J. Wassel, Change in tensile strength and ultimate elongation of neoprene and nitrile gloves after repeated exposures to acetone and thermal decontamination, in Am. Ind. Hyg. Conf. Expo. 2004.[17]

Gao P, Sun G, (University of California, Davis): “Self-Decontaminating Fabrics for Biological and Chemical Protection”, Presented at the 4th International Conference of Safety & Protective Fabrics to be held in Pittsburgh, PA October 26 – 27, 2004.[53]

El Ayouby N, Gao P, Wassell JT, Hall RC “Effect of Cycles of Contamination and Decontamination on Chemical Glove Performance”, poster presented at ASTM Eighth Symposium on Performance of Protective Clothing: Global Needs and Emerging Markets, Tampa, FL, January 13-14, 2004.[54]

Vo, E., development of colorimetric indicators: a new technique to determine glutaraldehyde and alkaline glutaraldehyde contamination, in Working Partnerships: Applying research to Practice, NORA Symposium. 2003: Washington, DC.[21]

Chen, C.C., et al., Evaluating dermal exposure hazards for assignment of skin notations, in American Industrial Hygiene Conference and Expo. 2003.[31]

Liu, Y., et al., Effectiveness of decontamination Products and Nitrile gloves in reducing Isocyanate Skin Exposure in Auto Body Shops: A Pilot Assessment, in Am. Ind. hyg. Conf. Expo. 2002.[11]

Vo, E., T. Klinger, and Z. Zhuang, Development of a glove end of service life indicator for weak organic and inorganic acids. , in Proceedings of the International Conference on Occupational and Environmental Exposures of skin to Chemicals: Science & Policy, September 8-11. 2002 NIOSH Morgantown, WV: Arlington, VA.[12]

Boeniger, M., et al., Novel Uses of Sorbent Filters to Assess Potential Skin Exposures, in Am. Ind. Hyg. Conf. Expo. 2002.[15]

Vo, E., Development of colorimetric indicators: a new technique to determine glutaraldehyde and alkaline glutaraldehyde contamination, in Proceedings of the International Conference on Occupational and Environmental Exposures of Skin to Chemicals: Science & Policy, September 8-11. 2002, NIOSH, Morgantown, WV: Arlington, VA.[18]

Chen, C., M. Boeniger, and H. Ahlers, A mathematical approach for evaluating dermal exposure and facilitating assignment of skin notations, in Proceedings of the International Conference on Occupational and Environmental Exposures of Skin to Chemicals: Science & Policy, Sep 8-11. 2002: Arlington, VA.[30]

*Invention disclosures / copyrights*

An Employee Invention Report (I-015-05) for the passive aerosol sampler was submitted to CDC Technology Transfer Office in March 2005.

Canadian Copyright "COMPUTER SOFTWARE FOR AUTOMATING PERMEATION TESTING DATA ANALYSIS – VERSION 2"
http://strategis.ic.gc.ca/app/cipo/copyrights/details.do%3bjsessionid=0000VX54Ruad7r56vbm9qLa29pp:1247nfca5?fileNum=1040562&type=1&language=eng

*NIOSH Scientific Information Products*

Permeation Calculator Version 2.4
Department of Health and Human Services (DHHS) (NIOSH) Publication No. 2007 - 143C [14]

Program researchers contributed to two main NIOSH nanotechnology documents (http://www.cdc.gov/niosh/docs/2007-123/ and http://www.cdc.gov/niosh/topics/nanotech/safenano/ that focus on protective clothing. [55, 56]

## 4.2 Improve Emergency Responder Protective Clothing to Reduce Exposure to Thermal, Biological, and Chemical Dermal Hazards

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### Issue

The hazards encountered by the nation's emergency responders are severe and continuously changing. Thermal, chemical and biological hazards and the numerous combinations represent a major challenge for PPT. Consequently, protective technologies available for the responder community have many gaps and lack sufficient standards based on quality science.

### Approach

In 2001 the PPT Program began work on identifying important PPT issues for emergency responders. Through stakeholder meetings, individual interviews and a request for written comments on its website, information was collected about responder knowledge, attitudes and workplace behaviors related to PPT. One stakeholder meeting involved 16 emergency responders who came together to develop a 5-year concept research plan of activities for protective clothing.[57]

The September 11, 2001 attacks on the World Trade Center (WTC) and Pentagon resulted in an increased emphasis on initiatives relative to fire services and emergency response personnel. In December 2001, the PPT Program sponsored a conference to address specific PPT issues from the WTC and Pentagon events. At the conference 150 participants provided information to determine what could be learned about protecting the life and health of emergency workers who respond to terrorist attacks.[58, 59]

As a separate effort the PPT Program also funded Pennsylvania State University to compile PPE procedures used at the terrorist events in order to identify gaps for research, standards, and guidance.

In addition to analysis of available statistics about exposure, injuries and fatalities, the PPT Program is proactive in finding ways to create opportunities to share information with stakeholders. An example is the PPT Program active involvement in IAB activities where emergency responders meet with federal agencies several times a year to exchange information.

A tactical focus of the PPT Program is active participation with SDOs. Program personnel have lead roles with NFPA standard committees, and task groups. PPT scientists provide the expertise and research to support development of performance criteria, testing methods and quality standards for emergency responder protective clothing and equipment. The partnership with NFPA is covered by a formal Memorandum of Understanding (MOU).

Similarly, the Program established an MOU with ASTM International to address the application of advanced technology for standards for protective clothing and equipment. As with NFPA, PPT personnel are committee members and work on task groups. Although the agreement has only been in place since 2006, PPT Program researchers and scientists have advanced several work items for standards developments activities.

The PPT Program, through a contract with North Carolina State University, conducted research to obtain a better understanding of the nature of fire fighter burns under the protective ensemble without evidence of clothing damage. The objective was to develop performance criteria recommendations and to design and validate a test apparatus to predict burn injuries from stored thermal energy in fire fighting protective ensembles (bunker gear). This research will increase the knowledge regarding unexplained burns to firefighters operating in routine and ordinary fire ground environments. Although these burns are not as severe as those found under emergency conditions, which cause firefighter deaths and injuries, these conditions constitute the much larger proportion of lost time from fire ground injuries.

The PPT Program conducted a literature search to obtain a better understanding of the nature of fire fighter burns under the ensemble occurring without evidence of clothing damage. Burn injury data from incidences not classified as emergency conditions were included in the search. The research contributed to the design of a test method to mimic circumstances found in firefighting. This test method was submitted to the ASTM F23 Committee in 2006 as a proposed new test method entitled "Test Method for Measuring the Transmitted and Stored Energy of Firefighter Protective Clothing Material Systems." The test method has gone through several ballot cycles and is projected to be formerly released as a new ASTM Test Method in 2008. Once released by ASTM, this test method will be incorporated into the next edition of NFPA 1971 Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting.[60]

The NFPA Fire Protection Research Foundation received a recent award from the DHS Fire Safety Research Grant Program to conduct interlaboratory testing using the stored thermal energy test method and testing apparatus designed and built under the PPT Program. The interlaboratory testing will serve to validate the repeatability of the test method results. Through an IAA with NFPA Fire Protection Research Foundation and NIOSH, PPT Program representatives are serving as Technical Program Managers to the NFPA Fire Protection Research Foundation for the effort.

The other research initiative is designed to support the development of advanced technology to address performance requirement gaps in NFPA 1999, Standard on Protective Clothing for Emergency Medical Operations.[61] This standard addresses gloves, garments, eye/face protection, footwear, and head protection for operations of both first responders to emergency medical operations and first receivers at hospitals. The research conducted by the PPT Program involved surveying emergency medical needs and patterns of PPT use for protection against blood or other liquid borne pathogens, understanding protection needs, recommending generic design and performance criteria and conducting research to establish appropriate methods and criteria based on product testing.

**Output and Transfer Highlights**

After the terrorist attacks of September 11, 2001, the Program obtained much of the PPE guidelines and information that were made available to the responding emergency workers at both the Pentagon and the WTC. The content of these materials was analyzed and a composite document was compiled that contained all of the major guidelines. These guidelines were reviewed for their appropriateness by an expert panel assembled for that purpose. Then, the Program contracted with the Rand Corporation to prepare four reports analyzing the gaps in emergency worker protection information that was available to those workers in 2001. The PPT Program released these reports under the title "Protecting Emergency Responders" (http://www.cdc.gov/niosh/npptl/guidancedocs/rand.html):[62-65]

- Protecting Emergency Responders: Lessons Learned from Terrorist Attacks
- Protecting Emergency Responders, Volume 2: Community Views of Safety and Health Risks and Personal Protection Needs
- Protecting Emergency Responders, Volume 3: Safety Management in Disaster and Terrorism Response
- Personal Protective Equipment Guidelines for Structural Collapse Events, RAND Volume 4

The PPT Program further contracted the International Association of Fire Fighters (IAFF) to provide a comprehensive report on the specific protection needs for the evolving fire service (A Review of Modern Fire Services Hazards and Protection Needs, IAFF Report to NPPTL, Oct 2003).[66] The objective was to identify the need for new product technology, specifications, and evaluation methods, use practices, and care procedures that enable the firefighter of the future to be safe and equipped with state of the art PPE. The needs covered a range of activities beyond structural fire fighting such as emergency medical care, technical rescue, hazardous materials emergency response, and a number of special operations. Specific hazards were identified for mission area and evaluated to determine how current product technology and available standards addressed the needs. The IAFF report made a number of recommendations for setting priorities for research and standards development. Risk assessment was used to identify gaps in protection and to focus on new and emerging technologies that may solve identified problems.

In a separate effort, North Carolina State University performed a comprehensive review of test methodology and performance requirements for fire and emergency services protective clothing. The findings of this effort identified a number of areas where new tests were needed or improvements in existing tests were recommended. This information is contained in Barker, R., A Review of Gaps and Limitations in Test Methods for First Responder Protective Clothing and Equipment. NIOSH Report, North Carolina. Jan 2005.[67]

Other NIOSH Safety and Health Topic Emergency Response Resources (http://www.cdc.gov/niosh/topics/emres/default.html)[68] internet site include considerable guidance and information related to the selection and use of protective ensembles. Categories include:

- Emergency Responders (http://www.cdc.gov/niosh/topics/emres/responders.html)[69]
- Terrorism Response (http://www.cdc.gov/niosh/topics/emres/terrorresp.html)[70]
- Natural Disasters – Personal Protective Equipment (http://www.cdc.gov/niosh/topics/emres/natural.html#ppe)[71]
- Disaster Site Management (http://www.cdc.gov/niosh/topics/emres/sitemgt.html)[72]
- Personal Protective Equipment (http://www.cdc.gov/niosh/topics/emres/ppe.html)[73]
- Chemical Agent Information (http://www.cdc.gov/niosh/topics/emres/chemagent.html)[74]

The PPT Program was the primary sponsor for a conference entitled, Advanced Personal Protective Equipment: Challenges in Protecting First Responders on October 16-18, 2005 at Virginia Tech.[75] Approximately 150 individuals participated in the conference, including 42 emergency responders. Other participants were stakeholders and researchers, including PPT Program researchers. The objective of the conference was to bring together emergency responders, government agencies, standards organizations, and personal protective equipment (PPE) manufacturers to exchange information, learn about PPE technologies and their applications to threats and to discuss other areas of mutual interest. The emphasis of the conference was on practical issues of threat accommodation, standards, regulations, applications of best practices, manufacturing and distribution issues, PPE decision-making and purchasing, and multi-PPE integration.

A list of PPT Sponsored conferences is provided as Appendix M.

**Intermediate Outcomes**

The PPT Program has contributed both to ASTM and NFPA Technical Committees on which it participates. This has included attendance at approximately 60 different meetings since 2001. PPT input to this group has taken the form of offered expertise as well as direct involvement through research support to specific standards development activities. A notable effort was the project "Improved Criteria for Emergency Medical Operations Protective Clothing," where several segments of the existing NFPA 1999[61]were rewritten as the consequence of PPT involvement that included an assessment of end user needs, development of test methodology, evaluation of PPT products for Emergency Medical Technicians (EMTs), and the recommendation of specific performance criteria.

A listing of NFPA and ASTM standards using PPT program outputs include:

- ASTM F2588-06 *Standard Test Method for Man-In-Simulant Test (MIST) for Protective Ensembles* – This test provides a method for evaluating overall integrity of protective ensembles against vapors in Chemical, Biological, Radiological, and Nuclear (CBRN) environments.[76]
- NFPA 1851, *Standard on Selection, Care and Maintenance of Structural Fire Fighting Protective* Ensembles (2007 Edition) – This document specifies minimum selection, care, and maintenance requirements for structural fire fighting protective ensembles, and the individual ensemble elements that include coats, trousers, coveralls, helmets, gloves, footwear, and interface components that are compliant with NFPA 1971. This standard is a companion document for NFPA 1971, *Standard on Protective Ensemble for Structural Fire Fighting.*[77]
- NFPA 1951, *Standard on Protective Ensemble for Technical Rescue Operations* (2007 Edition) – Based on work begun in 1997, this standard answers the need for personal protective equipment for fire and emergency services personnel operating at technical rescue incidents involving building or structural collapse, vehicle accidents, confined spaces, trench cave-ins, scaffolding collapses, high angle climbing accidents, and similar incidents. This standard now includes a CBRN technical rescue ensemble to provide

protection from CBRN incidents during terrorism operations. This standard requires the use of NIOSH certified CBRN APR/PAPR.[78]

- NFPA 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting* (2007 Edition) – NPPTL contributed heavily to the sixth revision of this standard, particularly to address CBRN protection. This standard establishes minimum levels of protection for fire fighting personnel assigned to fire department operations including but not limited to structural fire fighting, proximity fire fighting, rescue, emergency medical, and other emergency first responder functions.
- NFPA 1991, *Standard on Vapor-Protective Ensembles for Hazardous Materials Emergencies* (2005 Edition) – Based on work begun in 1986, this standard specifies the minimum requirements for the design, performance, testing, and certification of vapor-protective ensembles and individual protective elements for chemical vapor protection for fire and emergency service personnel. Additional optional criteria are provided for ensembles and individual protective elements that provide protection for chemical flash fire escape, liquefied gas, chemical and biological warfare agents, and chemical and biological terrorism incidents.[79]
- NFPA 1992, *Standard on Liquid Splash-Protective Ensembles and Clothing for Hazardous Materials Emergencies* (2005 Edition) – Based on work begun in 1985, this standard specifies minimum requirements for the design, performance, testing, documentation, and certification for liquid splash-protective ensembles, ensemble elements, and protective clothing used by emergency response personnel during hazardous materials incidents.[80]
- NFPA 1994, *Standard on Protective Ensembles for First Responders to CBRN Terrorism Incident*s (2007 Edition) – Based on work begun in 1998, this standard specifies the minimum requirements for the design, performance, testing, and certification of protective ensembles for fire and emergency services personnel operating at domestic terrorism incidents involving dual-use industrial chemicals, chemical terrorism agents, or biological terrorism agents. The intent is that the ensembles would be available in quantity, easily donned and used, and designed for single exposure use.[81]
- NFPA 1999, *Standard on Protective Clothing for Emergency Medical Operations* (2008 Edition) – As indicated above, the PPT Program provided resources to provide a significant revision of the this standards to address first responder and medical first receiver needs in providing emergency patient care and transport.[61]

The PPT Program is involved in the IAB. The IAB recommends directions for standards development and other research on equipment used by responders. Since 2001, Program staff has provided leadership in the Federal Coordinating Committee, the Personal Protective & Operational Equipment Subgroup, and made contributions to maintaining the Board's Standardized Equipment List.

The Responder Knowledge Base (RKB)[82] is an independent but government-sponsored online database of first responder PPT and other equipment. The RKB places a heavy emphasis on product compliance with existing standards. It transfers PPT Program standards developments and product evaluations to end users. Products listed in the RKB are aligned with the both the authorized equipment list (AEL) set by Department of Homeland Security (DHS) and the standardized equipment list (SEL) established by the IAB.

## What's Next?

The PPT Program will investigate pretreatment or conditioning methods for protective clothing testing to simulate the wear life of the clothing. Clothing barrier performance can change after it becomes worn. The first year of the effort will involve documenting clothing wear that occurs from repeated use and evaluation of potential techniques for simulating the types of observed wear. The second year of effort will address validation and implementation of recommended preconditioning techniques into NFPA and ASTM protective clothing standards.

The PPT Program is identifying additional opportunities to support standards development activities either through direct input to the SDOs or projects that meet SDO committee needs. Where new technology of interest is identified, evaluations will be conducted. The PPT Program will also respond to industry needs to improve test methods and investigate problems with protective clothing and equipment that affect dermal protection.

The PPT Program will maintain an active role with the IAB. This will enable PPT Program researchers to continue interaction with responders to learn about their PPT issues and needs.

**List of Outputs**

*Peer Reviewed Publications*

Gao P, King WP, Shaffer R [2007]. Review of Chamber Design Requirements for Testing of Personal Protective Clothing Ensembles. J Occup Environ Hyg. 4(8):562-571.[83]

Coca A, Roberge R, Shepherd A, Powell JB, Stull JO, Williams WJ [2007] “Ergonomic Comparison Of A Chem/Bio Prototype Firefighter Ensemble And A Standard Ensemble” submitted to the European Journal of Applied Physiology.[84]

*Conferences and Presentations*

A.Coca, R. Roberge, A. Shepherd, J.B. Powell, N. Shriver, J.O. Stull, E. Sinkule, and W.J. Williams. Ergonomic comparison of a chem/bio prototype firefighter ensemble and a standard ensemble. To be presented at the International Conference on Environmental Ergonomics (ICEE), Portoroz, Slovenia August 19-24, 2007 [85]

Turner NL, Chiou S, Zwiener J, Weaver D, Spahr J, (DSR), Sinkule E (NPPTL) [2007] Physiological Consequences of Leather and Rubber Boots in Men and Women Firefighters accepted for presentation at the annual meeting of the American College of Sports Medicine, May 30-June 2, 2007, in New Orleans, LA [86]

April 3, 2006 Ron Shaffer traveled to Gaithersburg, MD to give an invited talk at the National Institute of Standards and Technology Annual Conference on Fire Research. Ron gave the presentation titled “Personal Protective Technologies for First Responders”. The conference was attended by about 100 researchers from government, academia, and industry. [87]

El-Ayouby N, Ahlers H, Burgman M [2005]. Assessment of personal protective equipment needs of first responders during a structural collapse event. Occupational and Environmental Exposures of Skin to Chemicals, Stockholm, Sweden, June 12 -15, 2005.[88]

Shaffer, R., J. Szalajda, W.J. Williams. Fully integrated, intelligent ensembles for first responders: Development needs, R&D opportunities, and preliminary results. World Congress on Safety and Health at Work, Orlando, FL. 2005.[89]

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## 4.3 Investigate Physiological and Ergonomic Impact of Protective Ensembles on Individual Wearers in Affecting Worker Exposure to Dermal Hazards

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**Issue**

PPT designed to offer dermal protection often presents general physiological and/or ergonomic burdens for the user. Research is needed to better understand the relationships between the protection advanced technologies can provide and the increased burdens it may place on its user.

Furthermore, the ability of a worker's body to dissipate heat and thereby cool itself can be compromised when it is subject to high air temperatures, radiant heat sources, high humidity, direct physical contact with hot objects, or strenuous physical activities. Although protective clothing can be employed to protect workers from various workplace heat sources, wearing it often exacerbates the body's difficulty in cooling itself.

As a specific example, interior structural firefighting involves heavy physical exertion under extreme environmental conditions. Personal protective clothing and equipment can impose 50 lbs of weight on fire fighters and impede their evaporative cooling mechanisms. Occupational morbidity and mortality statistics reflect the impact of such stressors on fire service personnel.[1] Non-invasive physiological monitoring capabilities are needed to more precisely define cardiovascular and other physiological responses to the demands of fire fighting and to identify markers of impending physical problems.

**Approach**

Over the past decade, PPT Program researchers have engaged in various research projects to increase understanding of the physiological burden of wearing barrier clothing. The Office of Extramural Programs (OEP) has funded several grants in physiological monitoring research.[90-92] Other studies have been conducted to understand better the impact of wearing protective clothing to reduce exposure to dermal hazards.[93-98] The PPT Program has a focused research program evaluating firefighter ensembles.

The PPT Program developed a physiological protocol for conducting research studies to evaluate firefighter ensembles. Evaluation of the Project Homeland Emergency Response Operational and Equipment Systems (HEROES)[99] ensemble alongside conventional structural fire fighting protective ensembles in the PPT Program laboratory provided insight about the effects from wearing different firefighting ensembles, as well as providing direction to the developers of the technology. The Project HEROES ensemble was developed to provide passive CBRN protection to firefighters during ordinary structural firefighting. Given the challenges of creating barrier materials and ensemble interfaces, significant concerns existed about the additional burden of CBRN protection on firefighters, both ergonomically and physiologically.[99]

The PPT Program is completing a related research study to evaluate firefighter footwear weight. This study involves 50 firefighter test subjects using four styles of footwear and two different exercise protocols. Input from the fire service was used to help design the protocol. Initial findings of the study were presented to the NFPA Technical Committee responsible for managing standards requirements for structural firefighting protective footwear.

PPT Program research is proactive in factoring diversity considerations. The Project HEROES research recruited and used female subjects for the rigorous and physically demanding test protocol. For the footwear research additional funding was sought and obtained to include footwear specifically to accommodate the female firefighter.

**Output and Transfer Highlights**

PPT Program scientists presented research findings in eight peer-reviewed journal articles. In one three-month period, they provided 10 presentations to stakeholders at eight conferences and participated in four standards development activities.

The scientists meet regularly with industry representatives to keep current with emerging technologies and test equipment that could enhance research activities. The meetings below held in July 2007 are examples of these activities provided in the list of outputs.

In July 2007, The PPT Program researchers attended a meeting at W.L. Gore and Associates, in Elkton, Maryland to discuss the TSWG Toxic Industrial Chemicals (TICs) Project. The discussion focused on current inadequacies and problems with chemical permeation testing and potential solutions to improve the repeatability and reproducibility of the method.

During July 2007, The PPT Program researchers met with LifeSync Corporation. LifeSync manufactures a wearable physiological monitoring system that collects data such as heart rate and breathing rate. The question was whether the physiological monitoring technology would be able to send a data signal past the steel walls and Plexiglas window of the environmental chamber. The monitoring equipment functioned adequately and will be considered for purchase for use in the physiological test protocol of the mine refuge chambers.

**Intermediate Outcomes**

The PPT Program Physiological Protocol is setting the industry standard. It has been approved as an ASTM standard practice for physiological evaluation of protective ensembles based on research conducted in the PPT Program laboratory. This standard will promote physiological testing consistency in the protective clothing industry. The standard is expected to be published in 2007.

The Project HEROES evaluation shows that PPT products on the market are affected in positive ways by our research. Increased industry understanding of the tradeoffs for barrier clothing used for reduction of dermal exposures is leading to better protection for workers.[66]

**What's Next?**

The PPT Program research physiology laboratory established in 2005 uses state-of-the-art equipment for determining the work capacity of human subjects. Oxygen and carbon dioxide levels in the human subjects' exhaled breath can be measured as they use a treadmill or electronic cycle ergometer. Additional physiological data can be measured using advanced technology, a cloth vest equipped with sensors sending key data to a computer via wireless technology. Data gathered will assist PPT Program researchers in developing a predictive physiological stress index and models that may be used to evaluate future prototype protective garments.

The PPT Program research physiology laboratory conducts studies of different ensembles where technological improvements have been identified. This capability is a core component of future research planned to reduce exposure to dermal hazards.

The PPT Program is identifying other opportunities to evaluate dermal PPT. New projects are being established to evaluate heat stress and the potential for optimization of body cooling. Research will investigate various zones of the body to determine if effective cooling can be achieved through only a part of the human body. Research outputs could lead to optimal cooling devices of smaller, more efficient design.

A new project has been proposed to support the various NFPA committees on the performance requirements for the total heat loss (THL) test. This three-year research project consists of a series of experiments to be performed on human subjects wearing different types of emergency response PPE ensembles. The subjects will be instrumented such that physiological variables (core and skin temperature, heart rate, blood pressure, ECG, microclimate temperature) can be measured. After instrumentation, the subject will be required to don the PPE and exercise at a pre-determined work rate. The physiological variables obtained from these experiments will be related back to the THL numbers used to rate the PPE using THL apparatus. These experiments will be repeated for a representative set of commonly available PPE as well as prototype ensembles with additional chemical and biological hazard protection. The data collected during these experiments will be used to develop and validate physiological performance models to correlate the effects of ensemble THL characteristics on emergency responder performance.

In the PPT Program, different avenues for examining selection, use, and care of PPT will be investigated as it applies to different industry sectors. As each sector represents a different "trade" with its unique forums, tradeshows, publications, and other means for disseminating information, the PPT Program will explore the most efficient means for increasing awareness and interacting with the end user organizations and stakeholders within these respective industries. The PPT Program has demonstrated effectiveness with interacting with emergency responder organizations. This same approach will be applied to other sectors.

**List of Outputs**

*Peer Reviewed Publications*

Gao P, King W, Shaffer R [2007] Review of Chamber Design Requirements for Testing of Personal Protective Clothing Ensembles. Journal of Occupational and Environmental Hygiene, 4:8, 562-571.[83]

Coca A, Roberge R, Shepherd A, Powell JB, Stull JO, Williams WJ [2007] “Ergonomic Comparison Of A Chem/Bio Prototype Firefighter Ensemble And A Standard Ensemble” submitted  to the European Journal of Applied Physiology.[84]

Gao, P. and B. Tomasovic: Changes in tensile properties of neoprene and nitrile gloves after repeated exposures to acetone and thermal decontamination. Journal of Occupational & Environmental Hygiene, 2 (11): 543-552 (2005) [26]

Gao, P., N. Ayouby, and J.T. Wassell: Change in permeation parameters and the decontamination efficacy of three chemical protective gloves after repeated exposures to solvents and thermal decontaminations. American Journal of Industrial Medicine, 47 (2): 131-143 (2005).[16]

Bernard TE, Luecke CL, Schwartz SW, Kirkland KS, Ashley CD [2005]. WBGT clothing adjustments for four clothing ensembles under three relative humidity levels. J Occup Environ Hyg. 2(5):251-256.[91]

Belard L, Beeckman DC, Hause MG, Wassel JT, Stanevich RL [1996]. Hazardous waste abatement. Simulation in three controlled environments. Prof Saf. 41(6):33-36.[93]

*Conferences and Presentations*

A.Coca, R. Roberge, A. Shepherd, J.B. Powell, N. Shriver, J.O. Stull, E. Sinkule, and W.J.Williams. Ergonomic comparison of a chem/bio prototype firefighter ensemble and a standard ensemble. To be presented at the International Conference on EnvironmentalErgonomics (ICEE), Portoroz, Slovenia August 19-24, 2007.[85]

Gao P, Tomasovic B, (EG&G), Stein L, and Landsittel D, Gergel M, Patnaik R(ICS Laboratories, Inc., Brunswick, OH).  Statistical analyses of the decontamination efficacy of chemical protective clothing.  Presentation at the American Industrial Hygiene Conference and Exposition, Philadelphia, PA (2007) [100]

Shaffer, R., J. Szalajda, W.J. Williams. Fully integrated, intelligent ensembles for first responders: Development needs, R&D opportunities, and preliminary results. World Congress on Safety and Health at Work, Orlando, FL. (2005) [89]

The PPT researcher presented his work on decontamination efficacy of Chemical protective clothing Titled “Statistical analyses of the decontamination efficacy of chemical protective clothing" at the podium section "Personal Protective Equipment"and served as a monitor for this session. The PPT researcher also attended both Aerosol Technology Committee meeting and AIHA Personal Protective Clothing & Equipment Committee meeting during the conference. In addition, he served as a judge to select the best oral presentation for the "Aerosols" podium section.

Shaffer, R., J. Szalajda, W.J. Williams. Fully integrated, intelligent ensembles for first responders: Development needs, R&D opportunities, and preliminary results. World Congress on Safety and Health at Work, Orlando, FL. 2005.[89]

Williams, W.J. The Research Physiology Laboratory Capabilities and Current Projects. Invited presentation at the Session - Demands of the Job:  Monitoring the Physiological Response of Fire Fighters. The John P. Redmond Symposium, Honolulu, Hawaii, October 26, 2005.[101]

*Grant Outputs*

Bernard TE [2005]. Making heat stress assessment relevant again. NIOSH 2005 Jan; :1-48. Final Grant Report, Grant-Number-R01-OH-003983.[90]

Van Gelder-C; Pranger-A; Urias-A; Lo-R; Wiesmann-WP; Winchell-RJ; Kolka-M; Stachenfeld-N; Bogucki-S [2002]. Physiologic monitoring in extreme environments: application of micro-sensors and embedded processors to predict heat stress in fire fighters. Proceedings of SPIE. Biomedical Diagnostic, Guidance, and Surgical-Assist Systems IV. Bellingham, WA: Society of Photo-Optical Instrumentation Engineers (SPIE), 4615:71-81. Grant-Number-R43-OH-004173.[92]

McCammon J, Boudreau Y 1999]. Fire captain dies as a result of cardiac arrest while fighting a wildland/urban interface fire – California. NIOSH 1999 Nov:1-9.[97]

Echt A, Burroughs GE, Rubman MH, Booher DE [1998]. Carbon dioxide exposures to medical personnel as a result of wearing surgical isolation suits. Appl Occup Env Hyg. 13(2):87-90.[95]

Satcher D [1997]. Federal certification of personal protective equipment and clothing for firefighters and emergency response personnel. NIOSH 1997 Oct; :1-10.[98]

Bishop P, Reneau P, Ray P, Wang MQ, Smith J [1995]. Empirical Prediction of Physiological Response to Prolonged Work in Encapsulating Protective Clothing Human Performance Laboratory and Department of Industrial Engineering, University of Alabama, Tuscaloosa, Alabama 1995 Dec:85 pages. Final Grant Report, Grant-Number-R01-OH-03015.[94]

*Contract Reports*

International Personnel Protection [1996]. Personal Protective Clothing/Equipment Sizing and Fit Practices. International Personnel Protection, Inc., Austin, Texas, 180 pages. Task Order Report, Task-Order-9554554.[96]

*Standards Development Meetings*

June 19-20, 2007, The PPT program researchers attended the NFPA Technical Committee on Hazardous Materials Protective Clothing and Equipment in Miamisburg, OH. The TC discussed the future direction of the TC; Selection Care and Maintenance (SCAM) Documents; revision of NFPA 1991, 1992, and 1994. The Decision was made to short cycle NFPA 1991, 1992 and 1994 and produce revised versions within the same NFPA revision cycle. In addition, the TC decided that the SCAM document would follow the performance standards through the NFPA revision cycle by one year to ensure that the SCAM is always as up-to-date as possible. A presentation was given by Jeff Stull that outlined the TSWG TICs project. The presentation included the overall project objectives and PPT program's role in the project.

The PPT researcher presented Decontamination Efficiency of Filtering Facepiece Respirators research results to the ASTM Protective Clothing F23.30 Subcommittee. The subcommittee approved the creation of a work item and the submission of a draft for the next subcommittee ballot.

The PPT researcher gave the F23.30 Subcommittee on Chemical Hazards an update on the Permeation Calculator computer software, version 2.4. The software, approved by NIOSH OD, has been posted on NIOSH Website:
http://www.cdc.gov/niosh/npptl/PermeationCalculator/permeationcalc.html

In support of the TSWG Toxic Industrial Chemicals (TICs) Project, a new work item for a test method for the Measurement of Cumulative Permeation of Toxic Industrial Chemicals through Protective Clothing Materials was proposed to the F23.30 Sub-committee on Chemical Hazards. The subcommittee accepted the work item and the submission of a draft for the next subcommittee ballot

The initial round of balloting for the Air-Fed Ensemble standard was completed by the F23.30 Subcommittee, and a number of useful comments were received. The task group which is led by PPT researcher will incorporate the suggested changes and submit a revised draft for the next main committee ballot. The PPT Program is leading this effort due to the need to understand the CFR and the respiratory requirements as well as protective clothing protection requirements.

The F23.60 Subcommittee on Human Factors completed the initial main committee ballot on the Standard Practice for Determining the Physiological Responses of the Wearer to Protective Clothing Ensemble which was submitted by a PPT researcher. Two negative votes were received. After discussion with PPT researcher and the subcommittee, both submitters agreed to withdraw their negative ballot. Following minor editorial revisions, the standard will be assigned a number and then will likely be published within the next 2 months.

## References

1. BLS. *Census of Fatal Occupational Injuries*. http://www.bls.gov/iif/oshcfoil.htm 2006a [cited 2006 October 17].

2. BLS. *Industry and Injury Data*. http://www.bls.gov/iif/oshsum.htm 2006b [cited 2006 November 16].

3. Soderholm, S., *Proceedings of the International Conference on Occupational & Environmental Exposures of Skin to Chemicals: Science & Policy, Sep 8-11*, in *http://www.cdc.gov/niosh/topics/skin/conference/s5p3.html*. 2002, NORA Dermal Exposure Research Program (DERP).

4. Boeniger, M. and T. Klinger, *In-use testing and interpretation of chemical-resistant glove performance.* Appl Occup Environ Hyg, 2002. **17**(5): p. 368-378.

5. Code of Federal Regulations 29 CFR 1910.132, *Title 29 Labor, Part 1910.132 - Occupational Safety and Health Standards-Personal Protective Equipment*, in *http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9777*. 2003: U.S. Government Printing Office, Office of the Federal Register, Washington, DC.

6. Code of Federal Regulations 29 CFR 1910.120, *Title 29 Labor, Part 1910.120 - Occupational Safety and Health Standards-Hazardous waste operations and emergency response*, in *http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=standards&p_id=9765*. 2003: U.S. Government Printing Office, Office of the Federal Register, Washington, DC.

7. Carroll, T., *Decontamination matrix helps assess reuse potential for protective clothing.* Occup Health Safety, Mar, 1995. **64**(3): p. 54-58.

8. NIOSH. *NIOSH Control of Workplace Hazards for the 21st Century Conference, Mar 10-12*. http://www.cdc.gov/Niosh/updates/hazdconf.html 1998 [cited 2007 Aug].

9. NIOSH. *NIOSH Safety and Health Topic, Protective Clothing and Ensembles: http://www.cdc.gov/niosh/npptl/topics/protclothing/*. 2007 [cited 2007 Aug].

10. Collins-Hansen, I., et al., *Field evaluation of gloves and protective clothing against organic solvents during auto body spray painting*, in *Am. Ind. Hyg. Conf. Expo*. 2006.

11. Liu, Y., et al., *Effectiveness of decontamination Products and Nitrile gloves in reducing Isocyanate Skin Exposure in Auto Body Shops: A Pilot Assessment*, in *Am. Ind. hyg. Conf. Expo*. 2002.

12. Vo, E., T. Klinger, and Z. Zhuang, *Development of a glove end of service life indicator for weak organic and inorganic acids.* , in *Proceedings of the International Conference on Occupational and Environmental Exposures of skin to Chemicals: Science & Policy, September 8-11*. 2002 NIOSH Morgantown, WV: Arlington, VA.

13. AIHA, *Guideline for the Decontamination of Chemical Protective Clothing and Equipment*. AIHA Protective Clothing and Equipment Committee. 2005.

14. NIOSH. *Permeation Calculator Version 2.4, NIOSH Publication No. 2007-143C.* http://www.cdc.gov/niosh/npptl/PermeationCalculator/permeationcalc.html 2007 [cited 2007 Aug].

15. Boeniger, M., et al., *Novel Uses of Sorbent Filters to Assess Potential Skin Exposures*, in *Am. Ind. Hyg. Conf. Expo*. 2002.

16. Gao, P., N. El-Ayouby, and J. Wassel, *Change in permeation parameters and the decontamination efficacy of three chemical protective gloves,* http://www2a.cdc.gov/nioshtic-2/BuildQyr.asp?s1=20025921&View=e&. Am Ind Med, Apr, 2005. **47**(2): p. 131-143.

17. Gao, P., B. Tomasovic, and J. Wassel, *Change in tensile strength and ultimate elongation of neoprene and nitrile gloves after repeated exposures to acetone and thermal decontamination,* http://www2a.cdc.gov/nioshtic-2/BuildQyr.asp?s1=20024786&View=e&, in *Am. Ind. Hyg. Conf. Expo, May*. 2004, American Industrial Hygiene Association, Fairfax, VA: Atlanta, GA. p. 41-42.

18. Vo, E., *Development of colorimetric indicators: a new technique to determine glutaraldehyde and alkaline glutaraldehyde contamination*, in *Proceedings of the International Conference on Occupational and Environmental Exposures of Skin to Chemicals: Science & Policy, September 8-11*. 2002, NIOSH, Morgantown, WV: Arlington, VA.

19. Vo, E., *A new technique to determine organic and inorganic acid contamination.* Analyst, 2002. **127**(1): p. 178-182.

20. Vo, E., *A critique of Assumptions about Selecting Chemical-Resistant Gloves: A Case for Workplace Evaluation of Glove Efficacy.* Appl Occup Environ Hyg, 2002. **17**(5): p. 360-367.

21. Vo, E., *development of colorimetric indicators: a new technique to determine glutaraldehyde and alkaline glutaraldehyde contamination*, in *Working Partnerships: Applying research to Practice, NORA Symposium*. 2003: Washington, DC.

22. Vo, E., *Application of colorimetric indicators and thermo-hand method to determine base permeation through chemical protective gloves,* http://www2a.cdc.gov/nioshtic-2/BuildQyr.asp?s1=20025920&View=e&. J Occup Environ Hyg, Dec, 2004. **1**(12): p. 799-805.

23. Vo, E. and S. Berardinelli, *Determination of alkylamine permeation through protective gloves using aliphatic amine pads.* J Environ Monit, 1999. **1**(6): p. 545-456.

24. Vo, E., et al., *A quantitative study of aromatic amine permeation through protective gloves using amine adsorptive pads.* AIHA J , Nov-Dec, 2000. **61**(6): p. 837-841.

25. Vo, E., et al., *The thermo-hand method: evaluation of a new indicator pad for acid permeation of chemical protective gloves,* http://www2a.cdc.gov/nioshtic-2/BuildQyr.asp?s1=20023987&View=e&. Am Ind Hyg Assoc J, 2003. **64**(6): p. 771-776.

26. Gao, P. and B. Tomasovic, *Change in Tensile Properties of Neoprene and Nitrile Gloves After Repeated Exposure to Acetone and Thermal decontaminations,* http://www2a.cdc.gov/nioshtic-2/BuildQyr.asp?s1=20024786&View=e&. J Occup Environ Hyg, 2005. **2**(11): p. 543-552.

27. Pollock, D., et al., *Dusting off: NIOSH develops a new method to clean dust-soiled work clothes.* Rock Prod., 2005. **108**(3): p. 30-34.

28. Pollock, D., et al., *A new method to clean dust from soiled work clothes*, in *Proceedings of the 11th U.S./North American Mine Ventilation Symposium*. 2006: University Park, Pennsylvania, June 5-7.

29. Vo, E., S. Berardinelli, and R. Hall, *Recovery of some common solvents from protective clothing breakthrough indicator pads by microwave-solvent extraction and gas chromatography.* Analyst, 1999. **124**(6): p. 941-944.

30. Chen, C., M. Boeniger, and H. Ahlers, *A mathematical approach for evaluating dermal exposure and facilitating assignment of skin notations*, in *Proceedings of the International Conference on Occupational and Environmental Exposures of Skin to Chemicals: Science & Policy, Sep 8-11*. 2002: Arlington, VA.

31. Chen, C.C., et al., *Evaluating dermal exposure hazards for assignment of skin notations*, in *American Industrial Hygiene Conference and Expo*. 2003.

32. NIOSH. *NIOSH Safety and Health Topic: Skin Exposures & Effects, What's New?* http://www.cdc.gov/niosh/topics/skin/ 2007 [cited 2007 Aug].

33. NIOSH. *NIOSH Safety and Health Topic: Skin Exposures & Effects, Ongoing Skin Research*. http://www.cdc.gov/niosh/topics/skin/skinresearch.html 2007 [cited 2007 Aug].

34. NIOSH. *NIOSH Safety and Health Topic: Chemical Safety, NIOSH Databases and Other Resources*. http://www.cdc.gov/niosh/topics/chemical-safety/ 2007 [cited 2007 Aug].

35. NIOSH. *NIOSH Program Portfolio, Immune, Dermal and Infectious Diseases* http://www.cdc.gov/niosh/programs/ididisease.html 2007 [cited 2007 Aug].

36. NIOSH. *NIOSH Safety and Health Topic: Pesticide Illness & Injury Surveillance*. http://www.cdc.gov/niosh/topics/pesticides/ 2007 [cited 2007 Aug].

37. NIOSH, *Health Hazard Evaluation (HHE) report, HETA 95-0311-2593 Martin's Carstar, Inc. Lakewood, Colorado*, in *http://www.cdc.gov/niosh/hhe/reports/pdfs/1995-0311-2593.pdf*. 1995.

38. Gao, P., W. King, and R. Shaffer, *Review of Chamber Design Requirements for Testing of Personal Protective Clothing Ensembles.* Journal of Occupational and Environmental Hygiene, 2007(4): p. 562-571.

39. Fei, X., et al., *Pesticide detoxifying functions of N-halamine fabrics.* Archives of Environmental Contamination and Toxicology, 2006(51): p. 509-514.

40. Gao, P., et al., *Statistical analyses of the decontamination efficacy of chemical protective clothing. Presentation at the American Industrial Hygiene Conference and Exposition*. 2007: Philadelphia, PA.

41. Shaffer, R., *Update on Nanoparticle Filtration, Respirator, and PPE Research at NIOSH. Ask the Experts: An Update on NIOSH Research in Nanotechnology* in *Round table discussion at the American Industrial Hygiene Conference and Exposition, June 2-7*. 2007: Philadelphia, PA

42. Shaffer, R., *Overview of NIOSH Nanotechnology Research. Presentation at the Air & Waste Management Association, June 29*. 2007: Pittsburgh, PA.

43. Vo, E., et al., *Development of a Novel Colorimetric Indicator for Detecting Aldehydes.* The International Journal of Pure and Applied Analytical Chemistry, Atlanta, 2007(73): p. 87-94.

44. Shaffer, R., A. Rengasamy, and P. Gao, *Penetration of nanoparticles through respirators and protective clothing* in *Poster Presentation, presented at the International Conference on Nanotechnology Occupational & Environmental Health and Safety, Dec 4-6*. 2006: Cincinnati, OH.

45. Shaffer, R., P. Gao, and A. Rengasamy, *Penetration of nanoparticles through protective clothing and respirator filters. Presented at the Elevated Wind Studies International Conference, September 25–26* in *Arlington, VA*. 2006.

46. King, B. and P. Gao, *Coating evaluation for a newly developed passive aerosol sampler based on magnets for determination of particle penetration through protective ensembles. Presented at the American Industrial Hygiene Conference and Exposition, May 17*. 2006: Chicago, IL.

47. Shaffer, R., *Controls/PPE. Talk given at the Tech Talks session at the International Conference on Nanotechnology Occupational & Environmental Health and Safety, Dec 4-6* 2006: Cincinnati, OH

48. King, B. and P. Gao, *A passive aerosol sampler for evaluation of personal protective ensembles. Presented at the Advanced Personal Protective Equipment: Challenges in Protecting First Responders Conference, October16–18*. 2005: Blacksburg, VA

49. Gao, P., *Presented a poster entitled "Two new permeation parameters for evaluating decontamination efficacy of chemical protective clothing materials". "Occupational and Environmental Exposures of Skin to Chemicals" conference June 11 and June 14*. 2005: Stockholm, Sweden.

50. Vo, E., *Presented a poster entitled "Development of Colorimetric Indicators: A New Technique to Determine Acid, Base, and Aldehyde Contaminations". "Occupational and Environmental Exposures of Skin to Chemicals" conference June 11 and June 14*. 2005: Stockholm, Sweden.

51. Gao, P., B. Tomosovic, and D. Chung, *Development of a computer program for automating permeation testing data analysis. American Industrial Hygiene Conference & Exposition, May 23 – 27*. 2005: Anaheim, California.

52. Gao, P. and G. Sun, *"Detoxification of Carbamate Pesticides by Halamine Structures" presented at the 229th American Chemical Society National Meeting, March 13–17*. 2005: San Diego, California.

53. Gao, P. and G. Sun, *"Self-Decontaminating Fabrics for Biological and Chemical Protection", Presented at the 4th International Conference of Safety & Protective Fabrics, October 26 – 27*. 2005: Pittsburgh, PA.

54. El Ayouby, N., et al., *"Effect of Cycles of Contamination and Decontamination on Chemical Glove Performance", poster presented at ASTM Eighth Symposium on Performance of Protective Clothing: Global Needs and Emerging Markets, January 13-14*. 2004: Tampa, FL.

55. NIOSH. *Approaches to Safe Nanotechnology: An Information Exchange with NIOSH* http://www.cdc.gov/niosh/topics/nanotech/safenano/control.html 2007 [cited 2007 Aug].

56. NIOSH. *Progress Toward Safe Nanotechnology in the Workplace: NIOSH Publication No. 2007-123* http://www.cdc.gov/niosh/docs/2007-123/ , June 2007 [cited 2007 Aug].

57. Centers for Disease Control and Prevention (CDC), *2nd National Stakeholders' Meeting Report, April 10-11*, in *http://0-www.cdc.gov.mill1.sjlibrary.org/nedss/Archive/Stakeholder2/stakeholder_mtg_2.htm*. 2001, Centers for Disease Control and Prevention: Atlanta, GA.

58. NIOSH. *Fact Sheet: Protecting Workers at the World Trade Center Site, Response from the National Institute for Occupational Safety and Health* http://www.cdc.gov/niosh/02-143.html 2002 [cited 2007 Aug].

59. NIOSH. *NIOSH Safety and Health Topic: World Trade Center Response* http://www.cdc.gov/niosh/topics/wtc/ 2002 [cited 2007 Aug].

60. NFPA. *NFPA 1971: Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*. http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=1971&cookie%5Ftest=1 2007 [cited 2007 Aug].

61. NFPA. *NFPA 1999: Standard on Protective Clothing for Emergency Medical Operations*. http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=1999 2003 [cited 2007 Aug].

62. Jackson, B., et al., *Protecting Emergency Responders: Lessons Learned from Terrorist Attacks*. Conference Proceedings, CF-176-OSTP. 2002: RAND Corporation.

63. LaTourrette, T., et al., *Protecting Emergency Responders Volume 2*. Community Views of Safety and Health Risks and Personal Protection Needs, MR-1646-NIOSH. 2003: RAND Corporation. 142.

64. NIOSH, *Protecting Emergency Responders Volume 3, Safety Management in Disaster and Terrorism Response*. DHHS (NIOSH) Publication No. 2004-144. 2004: RAND. 119.

65. Willis, H., et al., *Protecting Emergency Responders Volume 4* Personal Protective Equipment Guidelines for Structural Collapse Events, MG-425-NIOSH. 2006: RAND Corporation. 83.

66. International Association of Fire Fighters (IAFF), *Project Heroes—Homeland Emergency Response Operational and Equipment Systems, http://www.cdc.gov/niosh/npptl/pdfs/ProjectHEROES.pdf*, in *Task 1: A Review of Modern Fire Service Hazards and Protection Needs. October 13*. 2003.

67. Barker, R., *A review of gaps and limitations in test methods for first responder protective clothing and equipment*, in *A Final Report presented to NPPTL, NIOSH. January 31*. 2005.

68. NIOSH. *NIOSH Safety and Health Topic: Emergency Response Resources*. http://www.cdc.gov/niosh/topics/emres/default.html 2007 [cited 2007 Aug].

69. NIOSH. *NIOSH Safety and Health Topic: Emergency Response Resources, Emergency Responders*. http://www.cdc.gov/niosh/topics/emres/responders.html 2007 [cited 2007 Aug].

70. NIOSH. *NIOSH Safety and Health Topic: Emergency Response Resources, Terrorism Response*. http://www.cdc.gov/niosh/topics/emres/terrorresp.html 2007 [cited 2007 Aug].

71. NIOSH. *NIOSH Safety and Health Topic: Emergency Response Resources, Natural Disasters, Personal Protective Equipment*. http://www.cdc.gov/niosh/topics/emres/natural.html#ppe 2007 [cited 2007 Aug].

72. NIOSH. *NIOSH Safety and Health Topic: Emergency Response Resources, Disaster Site Management*. http://www.cdc.gov/niosh/topics/emres/sitemgt.html 2007 [cited 2007 Aug].

73. NIOSH. *NIOSH Safety and Health Topic: Emergency Response Resources, Personal Protective Equipment*. http://www.cdc.gov/niosh/topics/emres/ppe.html 2007 [cited 2007 Aug].

74. NIOSH. *NIOSH Safety and Health Topic: Emergency Response Resources, Chemical Agent Information*. http://www.cdc.gov/niosh/topics/emres/chemagent.html 2007 [cited 2007 Aug].

75. Virginia Tech. *Advanced Personal Protective Equipment: Challenges in Protecting First Responders, October 16-18*. http://www.cpe.vt.edu/appe/program.html 2005 [cited 2007 Aug].

76. ASTM, *ASTM F2588-6, Standard Test Method for Man-In-Simulant Test (MIST) for Protective Ensembles* in *http://www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/REDLINE_PAGES/F2588.htm?E+mystore*. 2007.

77. NFPA. *NFPA 1851: Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural and Proximity Fire Fighting*. http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=1851 2008 [cited 2007 Aug].

78. NFPA. *NFPA 1951: Standard on Protective Ensembles for Technical Rescue Incidents*. http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=1951 2007 [cited 2007 Aug].

79. NFPA. *NFPA 1991: Standard on Vapor-Protective Ensembles for Hazardous Materials Emergencies*. http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=1991 2005 [cited 2007 Aug].

80. NFPA. *NFPA 1992: Standard on Liquid Splash-Protective Ensembles and Clothing for Hazardous Materials Emergencies*. http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=1992 2005 [cited 2007 Aug].

81. NFPA. *NFPA 1994: Standard on Protective Ensembles for First Responders to CBRN Terrorism Incidents*. http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=1994 2007 [cited 2007 Aug].

82. Department of Homeland Security (DHS). *Responder Knowledge Base (RKB)*. https://www.rkb.mipt.org/ 2007 [cited 2007 Aug].

83. Gao, P., W. King, and R. Shaffer, *Review of Chamber Design Requirements for Testing of Personal Protective Clothing Ensembles, http://www.informaworld.com/smpp/content?content=10.1080/15459620701448416*. Journal of Occupational and Environmental Hygiene, Aug, 2007. **4**(8): p. 562-571.

84. Coca, A., et al., *Ergonomic comparison of a chem/bio prototype firefighter ensemble and a standard ensemble.* Submitted to the European Journal of Applied Physiology, 2007.

85. Coca, A., et al., *Ergonomic comparison of a chem/bio prototype firefighter ensemble and a standard ensemble*, in *the International Conference on Environmental Ergonomics (ICEE), August 19-24*. 2007: Portoroz, Slovenia.

86. Turner, N., et al., *Physiological Consequences of Leather and Rubber Boots in Men and Women Firefighters accepted for presentation at the annual meeting of the American College of Sports Medicine, May 30-June 2*. 2007: New Orleans, LA.

87. Shaffer, R., *"Personal Protective Technologies for First Responders"Presented at National Institute of Standards and Technology Annual Conference on Fire Research* 2006: Gaithersburg, MD.

88. El-Ayouby, N., H. Ahlers, and M. Burgman, *Assessment of personal protective equipment needs of first responders during a structural collapse event.* , in *Occupational and Environmental Exposures of Skin to Chemicals, June 12-15*. 2005: Stockholm, Sweden.

89. Shaffer, R., J. Szalajda, and W. Williams, *Fully integrated, intelligent ensembles for first responders: Development needs, R&D opportunities, and preliminary results*, in *World Congress on Safety and Health at Work*. 2005: Orlando, FL.

90. Bernard, T., *Making heat stress assessment relevant again*, in *Final Grant Report, Grant-Number-R01-OH-003983, Jan*. 2005, NIOSH. p. 1-48.

91. Bernard, T., et al., *WBGT clothing adjustments for four clothing ensembles under three relative humidity levels.* J Occup Environ Hyg, 2005. **2**(5): p. 251-256.

92. Van Gelder, C., et al., *Physiologic monitoring in extreme environments: application of microsensors and embedded processors to predict heat stress in fire fighters*, in *Proceedings of SPIE. Biomedical Diagnostic, Guidance, and Surgical-assist Systems IV, Grant-Number-R43-OH-004173*. 2002, Society of Photo-Optical Instrumentation Engineers (SPIE): Belingham, WA, 4615. p. 71-81.

93. Belard, L., et al., *Hazardous waste abatement. Simulation in three controlled environments.* Professional Safety, 1996. **41**(6): p. 33-36.

94. Bishop, P., et al., *Empirical Prediction of Physiological Response to Prolonged Work in Encapsulating Protective Clothing*, in *Human Performance Laboratory and Department of Industrial Engineering, Dec, Final Grant Report, Grant-Number-R01-OH-03015.* 1995, University of Alabama, : Tuscaloosa, Alabama. p. 85.

95. Echt, A., et al., *Carbon dioxide exposures to medical personnel as a result of wearing surgical isolation suits.* Appl Occup Env Hyg, 1998. **13**(2): p. 87-90.

96. International Personnel Protection (IPP), *Personal Protective Clothing/Equipment Sizing and Fit Practices*, in *Task Order Report, Task-Order-9554554*. 1996, International Personnel Protection, Inc., : Austin, Texas. p. 180.

97. McCammon, J.B. and Y. Boudreau, *Fire captain dies as a result of cardiac arrest while fighting a wildland/urban interface fire – California, Nov*. 1999, NIOSH p. 1-9.

98. Satcher, D., *Federal certification of personal protective equipment and clothing for firefighters and emergency response personnel, Oct*. 1997, NIOSH. p. 1-10.

99. International Association of Fire Fighters (IAFF). *IAFF's Project HEROES*. http://www.iaff.org/hs/Project%20HEROES.htm 2007 [cited 2007 Aug].

100. Gao, P., et al., *Statistical analyses of the decontamination efficacy of chemical protective clothing*, in *Presentation at the American Industrial Hygiene Conference and Exposition*. 2007: Philadelphia, PA.

101. Williams, W., *The Research Physiology Laboratory Capabilities and Current Projects*, in *Invited presentation at the Session - Demands of the Job: Monitoring the Physiological Response of Fire Fighters, Oct 26*. 2005, The John P. Redmond Symposium: Honolulu, Hawaii.

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